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INTRODUCTION

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300F to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, CH98, is a promising candidate for gas turbine engines and is being studied in NASA's AST Program. For large disks, residual stresses generated during quenching from solution heat treatments are often reduced by a stabilization heat treatment, in which the disk is heated in the range of 1500 to 1600F for several hours followed by a static air cool and age. The reduction in residual stress levels lessens distortion during machining of disks. Previous work on CH98 has indicated that stabilization treatments will decrease creep capability (Ref. 1), however, tungsten additions appear to improve the creep capability of stabilized and aged CH98 (Ref. 2). In this study, a systematic variation of tungsten additions to CH98 was investigated. Specifically, the 1300F tensile, creep, and fatigue crack growth properties of stabilized CH98 were assessed with varying levels of tungsten additions.

MATERIAL & TEST PROCEDURE

The compositions of six experimental heats of CH98 studied in this paper are shown in Table 1. Alloys 1, 2, and 3 all have the base CH98 composition with target tungsten levels of 0, 1.5, and 3 weight percent. In addition to these compositions, three additional tungsten bearing alloys were made with reduced tantalum levels to offset density penalties associated with tungsten additions. Alloys 4 and 5 were designed to assess tungsten contents of 1.5 and 3 weight percent in a CH98 type alloy with a tantalum level of 1.5 weight percent. A tantalum content of 1.5% was chosen as it was thought to be necessary to maintain adequate crack growth resistance. Alloy 6 was included as it represents a midpoint in composition between high (3%) and low (1.5%) levels of tungsten and tantalum for alloys 2 through 5. Before any of the alloys were melted, the compositions were analyzed by Paul Reynolds of Pratt & Whitney to check gamma prime content, density, and alloy stability. Analysis of the target compositions indicated that the gamma prime content of all six alloys should be about 52%. Alloy stability, as measured by N_{V3}, was less than 2.35 which indicated that the alloy compositions were not prone to formation of embrittling phases. The estimated gamma prime solvi of these alloys were between 2150 and 2180F, while the estimated densities were between 0.295 and 0.300 lb/in^3. Tungsten additions tended to depress the solvus, and, as one might expect, higher levels of tungsten and tantalum increased density. All material in this study was produced from argon atomized powder which was consolidated by hot compaction at 1925F followed by extrusion at 1965F with a 6:1 reduction ratio. Specimen blanks were cut from the extrusions and HIPed at 2200F/30KSI/3HR to achieve a coarse grain size without introducing excessive porosity levels. After HIPing, the blanks were solutioned at 2125F for 1 hour followed by an air cool to achieve an initial cooling rate of about 250F/MIN to simulate production conditions. After solutioning the blanks were then stabilized at 1550F for 2 hours and finally aged at 1400F for 8 hours.

Tensile, creep and crack growth specimens were machined from the heat treated blanks. The tensile and creep specimens were identical with a cylindrical gage section measuring 0.160" in diameter by 0.750" long. Tensile tests were run at 1300F at a strain rate of 0.5%/minute through yield. Creep tests were run at 1300F and 90KSI. Crack growth rates were measured using a K_B Bar surface flaw specimen developed by Vanstone (Ref. 3). The K_B Bar had a rectangular cross section measuring 0.40" wide and 0.17" thick with a thin, semicircular surface flaw 0.015" in diameter located at the center of the 0.40" face. A precrack extending to a depth of about 0.030" (0.015" notch plus 0.015" crack) was introduced by high frequency cycling at room temperature before dwell testing at 1300F. The peak cyclic stress for precracking and testing was held constant throughout at a stress level of about 100KSI. A tension-tension dwell cycle was employed during testing at 1300F with a 180 second dwell at peak stress and an R-ratio of 0.1. Dwell crack growth rates were monitored using a DC potential drop technique from a K_{MAX} of 20 to 40KSI-IN$^{0.5}$ with two distinct calibration points per test.

RESULTS & DISCUSSION

The target grain size of the six alloys was 6 to 8 ASTM, however, metallurgical examination showed alloys 1 and 2 to be significantly finer, at ASTM 10, as seen in Table 2. Micrographs of alloys 1 and 6, Figure 1, clearly show the difference in grain size and also show that alloy 1 contains significant amounts of primary gamma prime indicating that the HIP at 2200F did not completely solution all gamma prime. Similarly, alloy 2 was also found to contain significant amounts of primary gamma prime.

The 1300F tensile data of all alloys HIPed at 2200F are summarized in Table 3. Alloys 3 and 5 failed at thermocouple welds and therefore the ductility and tensile strength values should be considered as minimums for these two alloys. Yield and tensile strength values are compared in Figure 2. Since yield strength is strongly dependent on grain size, alloys 1 and 2 (ASTM 10) have an advantage over alloys 3 through 6 (ASTM 8). Nevertheless, alloy 3 (with the highest tungsten plus tantalum level) had the highest yield strength, while alloy 4 (with the lowest tungsten plus tantalum level) had the lowest yield strength. This ranking suggests higher levels of tungsten and tantalum increase yield strength. Tensile strength appeared to follow a similar trend although the effect was less pronounced. The ductility of all alloys fell between 14 and 20% with the exceptions of alloys 3 and 5 which failed at thermocouple welds.

Creep data on the six alloys HIPed at 2200F was generated at 1300F/90KSI and is summarized in Table 4. Duplicate tests were run to about 0.5% and one of the alloy 3 tests was run to failure. The time to 0.2% creep, an important design consideration for disk operation, is presented graphically in Figure 3. From this data it is obvious that tungsten had a significant impact on the time to 0.2% creep. Alloy 3 (highest tungsten level) shows the best creep resistance, while alloy 1 (no tungsten) shows the worst creep resistance. Unlike yield strength, variations in grain size have been shown to have minimal impact on the time to 0.2% creep for disk alloys under these conditions (Ref. 4). To help quantify the effect of tungsten and tantalum variations, the time to 0.2% creep has been plotted against each of these two variables, Figures 4 and 5. These plots clearly show the direct correlation between tungsten and creep (R^2=0.90) and a lack of correlation between tantalum and creep (R^2=0.01) for the range of compositions studied. In addition , a multiple linear regression package using a stepwise forward selection technique (F=2.5) was employed to check a model including both tungsten and tantalum. The results of that analysis also indicated that tungsten was the only significant variable. As high tungsten levels can have an adverse impact on creep ductility in this class of alloys, one of the alloy 3 tests was run to failure and attained a life of 3689 hours with an elongation of 12% and a reduction in area of 15%. This test indicated that levels of tungsten up to 3% in CH98 do not significantly reduce creep ductility.

The 1300F dwell crack growth rates of the six alloys HIPed at 2200F were measured and are compared in Figure 6. As seen in this plot, the alloys fall into two groups. Alloys 1 and 2 have significantly higher crack growth rates than alloys 3 through 6. This difference was largely related to differences in grain size, rather than composition. Recall alloys 1 and 2 had a finer grain size, ASTM 10, while alloys 3 through 6 had a coarser grain size, ASTM 8. Previous work on CH98 has shown finer grain sizes will produce faster crack growth rates under these conditions (Ref. 1). To confirm this hypothesis, additional blanks of alloys 2 and 4 were HIPed at 2225F/30KSI/3HR and subsequently heat treated as before. The higher HIP temperature was designed to produce similar grain sizes in both alloys. Metallographic analysis showed the grain size of alloys 2 and 4 to be about ASTM 6 to 7 after HIPing at 2225F. Crack growth tests on alloys 2 and 4, HIPed at 2225F, were performed. A comparison of all data for alloys 2 and 4 is presented in Figure 7. The data shows the crack growth rates of alloys 2 and 4 are essentially equivalent when the grain sizes are similar.

SUMMARY & CONCLUSIONS

The effect of tungsten additions, up to 3 weight percent, on the 1300F tensile, creep, and dwell crack growth behavior of stabilized CH98, an advanced nickel-base disk alloy, were studied. Yield and ultimate tensile strength were improved by the addition of tungsten without any notable detriment to alloy ductility. The 0.2% creep time at 1300F/90KSI was dramatically increased by the addition of tungsten. The best tensile and creep results were achieved with the maximum tungsten level, 3%. Further, dwell crack growth resistance was not altered by the addition of tungsten.

Large disks often require a stabilization heat treatment to minimize distortion during machining. Therefore, the addition of tungsten to CH98 would appear to be warranted for large disks as tensile and creep properties improve with negligible impact on ductility and dwell crack growth. The 3% tungsten level increased the density of CH98 to 0.3lb/in^3 and probably represents a reasonable compromise between increased weight versus performance (tensile/creep) for larger subsonic aircraft.

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Table 1 Composition of the six alloys in weight percent.

ALLOY	C	Cr	Co	Mo	Ti	Al	B	Zr	W	Ta	Ni
1	0.049	11.6	17.9	2.9	4.0	3.9	0.030	0.050	0.01	2.90	BAL
2	0.046	11.4	18.4	2.9	4.0	3.8	0.028	0.045	1.40	2.90	BAL
3	0.047	11.4	18.0	2.9	3.9	3.7	0.030	0.047	3.00	2.90	BAL
4	0.044	11.3	18.6	2.9	4.0	3.8	0.029	0.043	1.40	1.60	BAL
5	0.054	11.3	18.7	2.9	3.9	3.8	0.029	0.058	3.00	1.50	BAL
6	0.043	11.5	17.9	2.9	4.0	3.9	0.030	0.048	2.24	2.27	BAL

Table 2 Grain size of the six alloys.		
ALLOY	ASTM GRAIN SIZE	HIP TEMPERATURE (F)
1	10.3	2200
2	9.7	2200
3	8.3	2200
4	8.3	2200
5	8.3	2200
6	7.6	2200

Table 3 1300F tensile data.			
ALLOY	0.2% YIELD	ULTIMATE	ELONGATION
(---)	(KSI)	(KSI)	(%)
1	136	157	16
2	141	161	14
3	146	167	9
4	134	160	20
5	141	166	12
6	141	167	14
NOTE: ALLOY 3 & 5 FAILED AT TC WELDS			

Table 4 Alloy creep data (HRS).			
ALLOY-SPEC	0.10%	0.20%	0.40%
1-A	22	62	147
1-B	79	128	202
2-A	16	59	230
2-B	279	366	435
3-A	351	565	852
3-B	358	527	775
4-A	29	106	289
4-B	205	297	423
5-A	313	509	862
5-B	184	349	562
6-A	165	311	513
6-B	219	349	539

Fig. 1 Microstructure of alloy 1 (top) and alloy 6 (bottom).

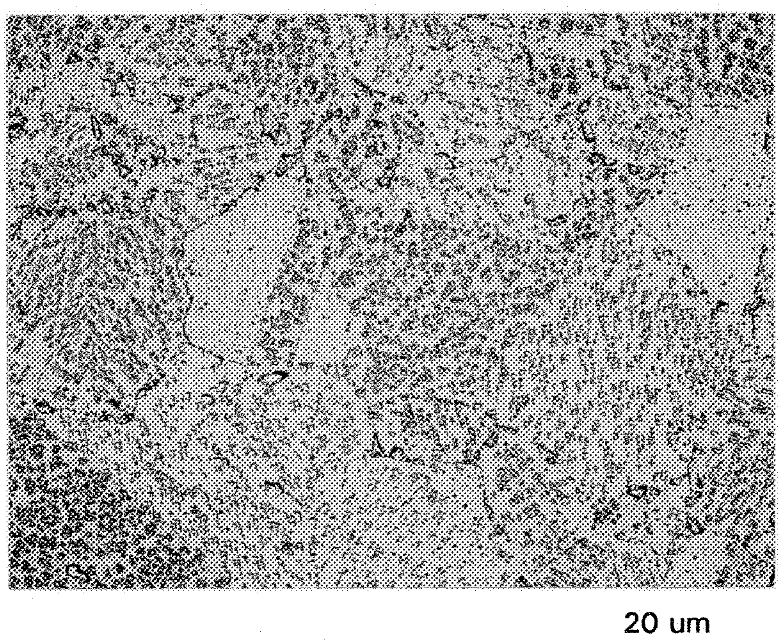


Fig. 2 1300F tensile data for the six alloys.

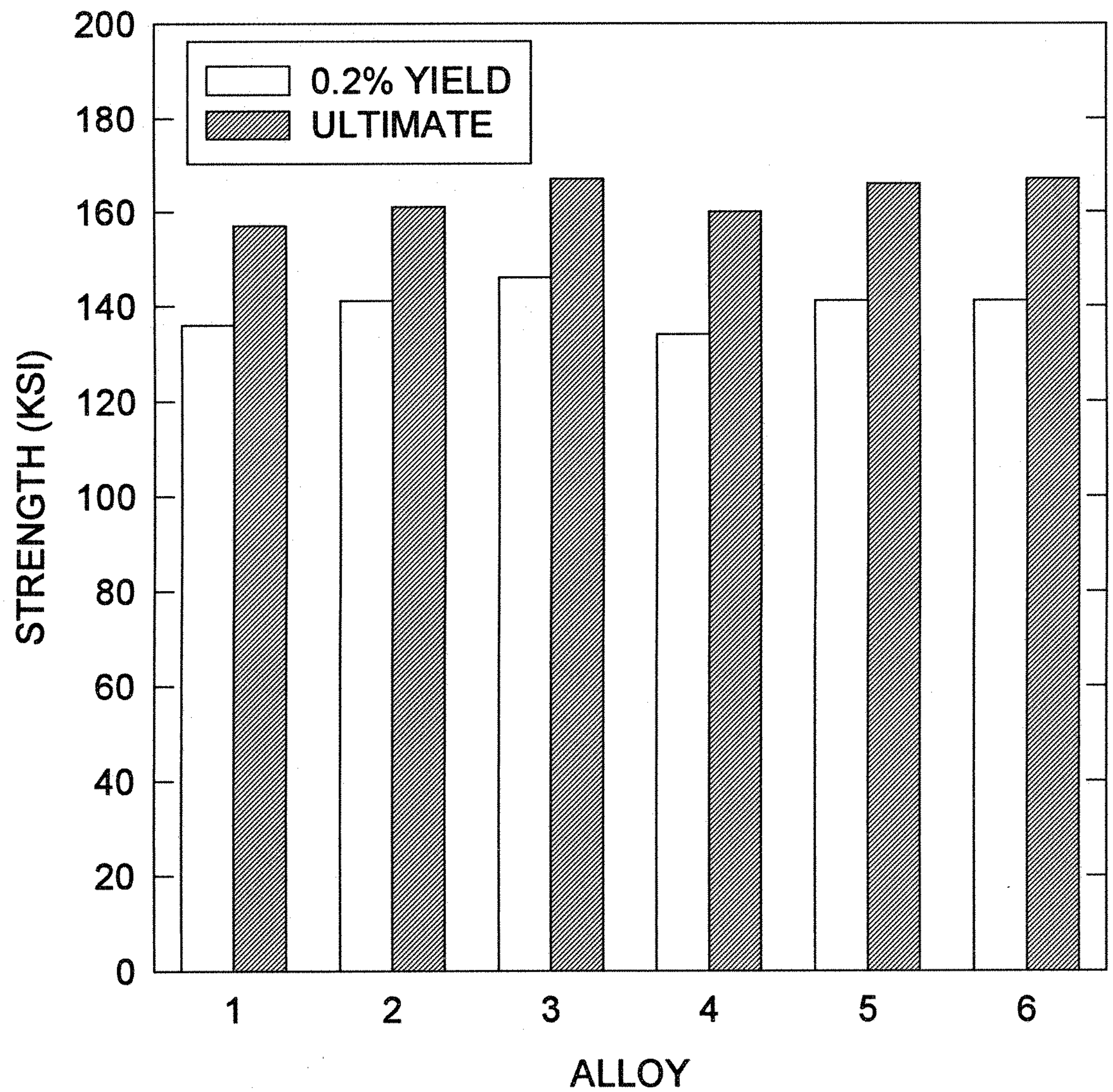


Fig. 3 0.2% 1300F/90KSI creep data for the six alloys.

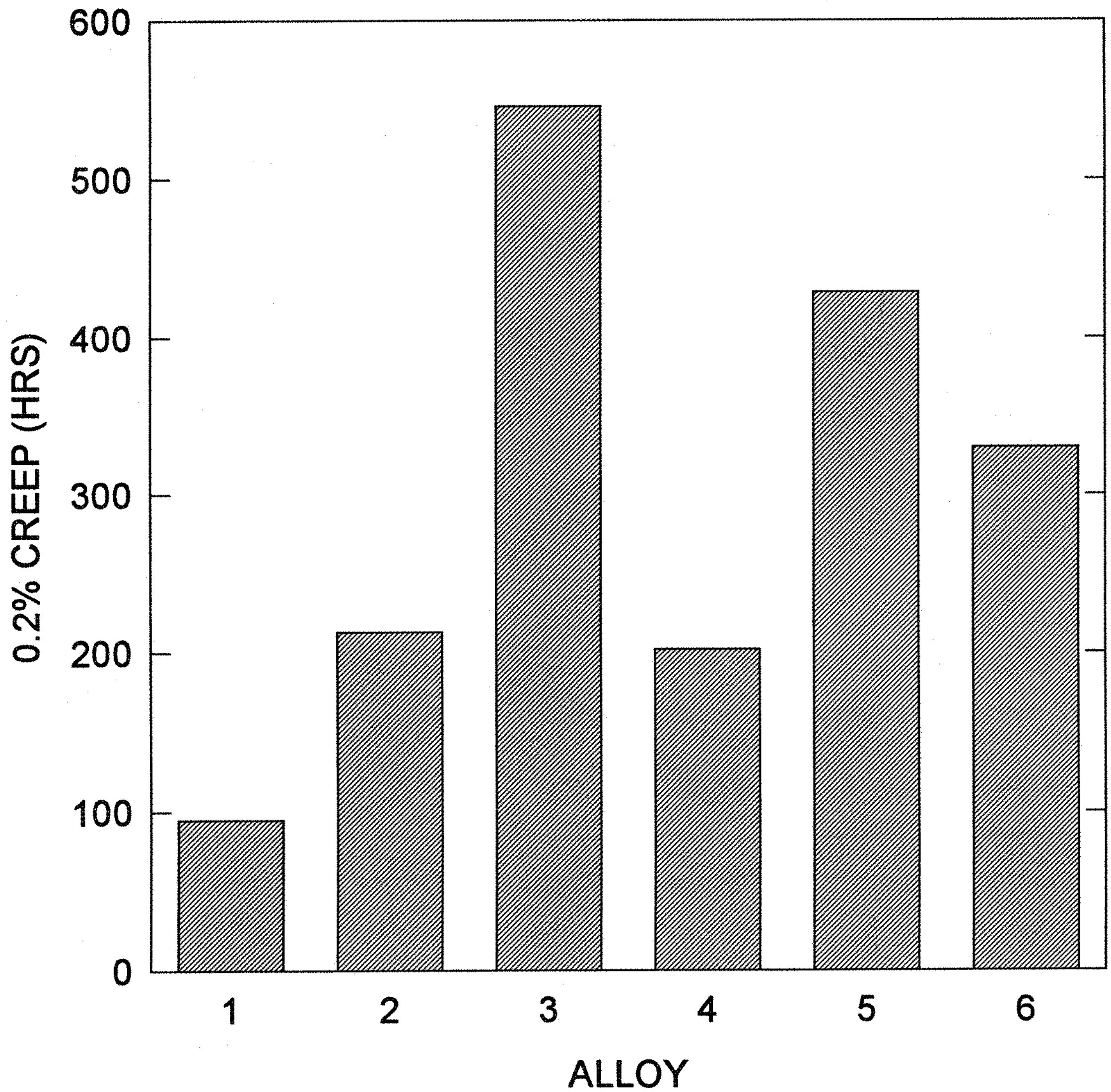


Fig. 4 The effect of tungsten on 1300F/90KSI creep.

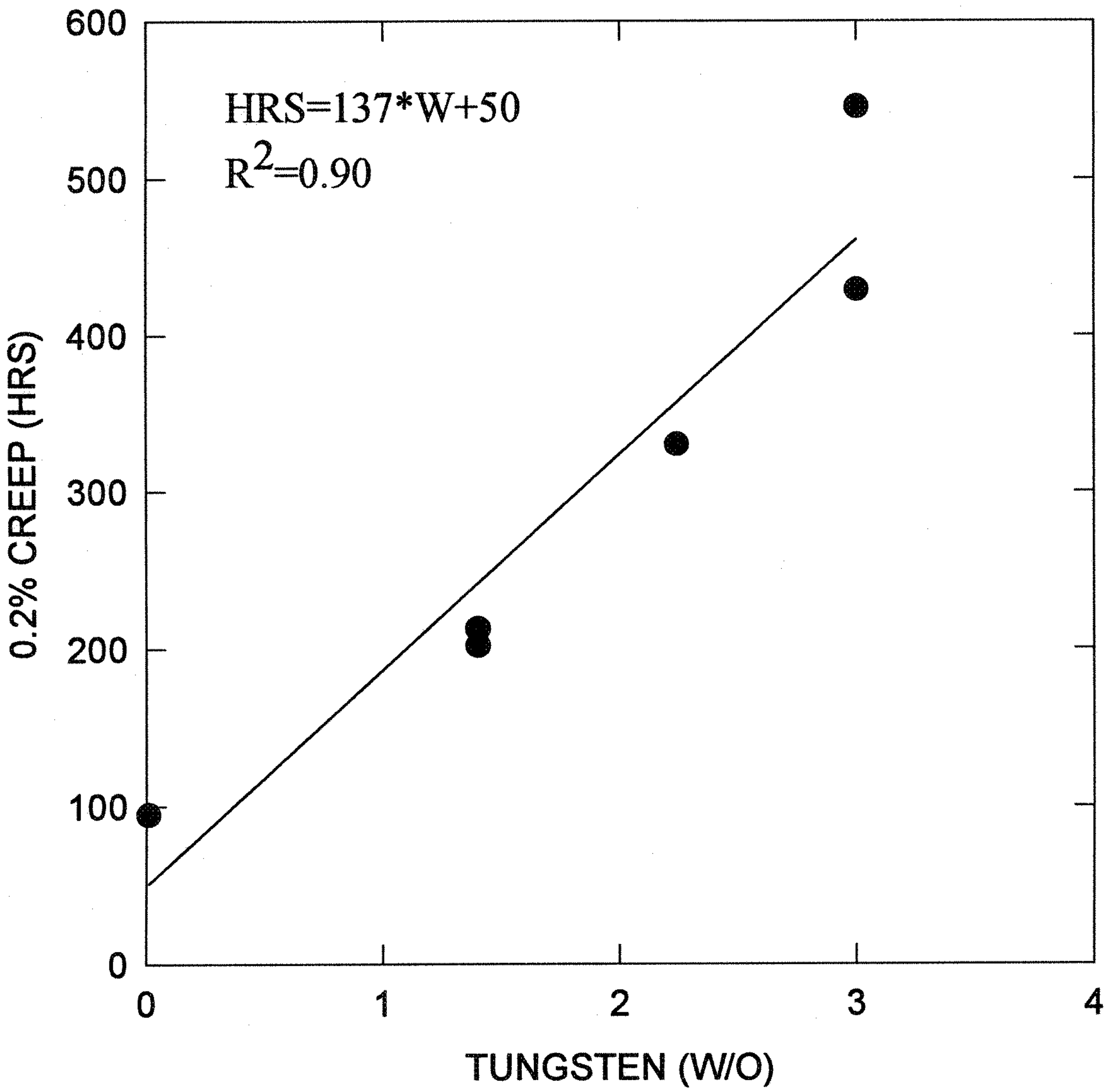


Fig. 5 The effect of tantalum on 1300F/90KSI creep.

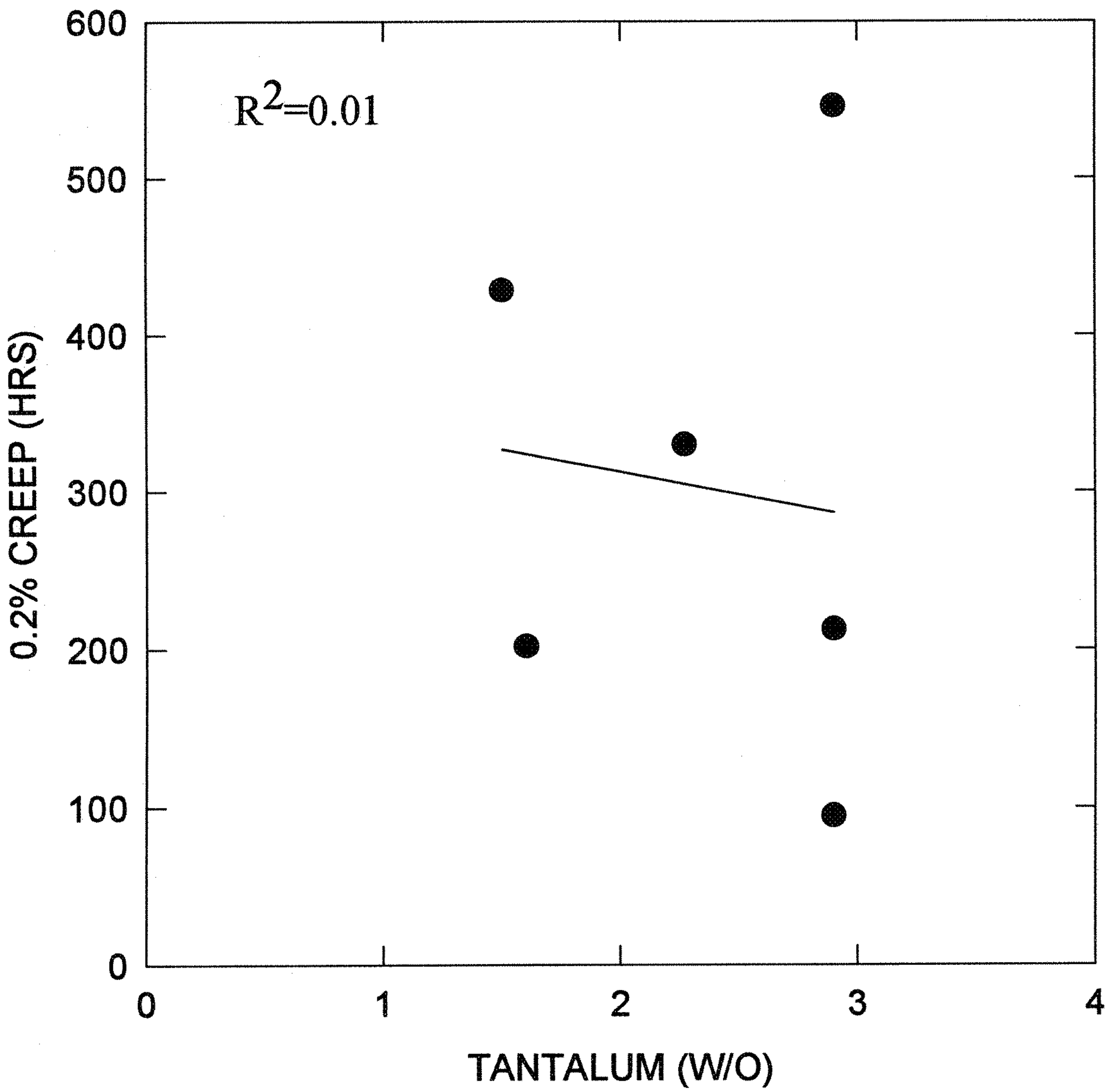


Fig. 6 1300F/180SEC dwell crack growth rates.

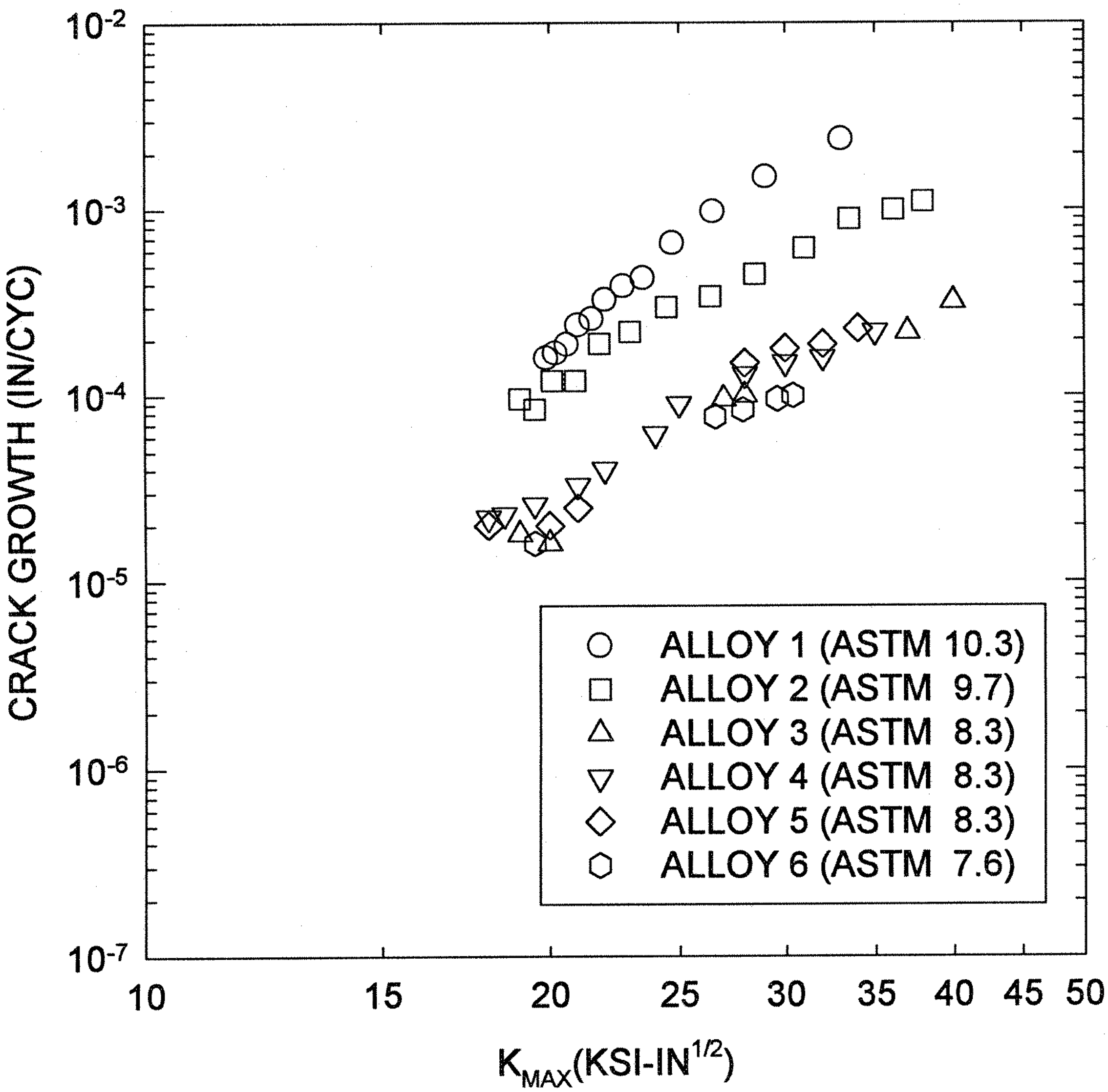
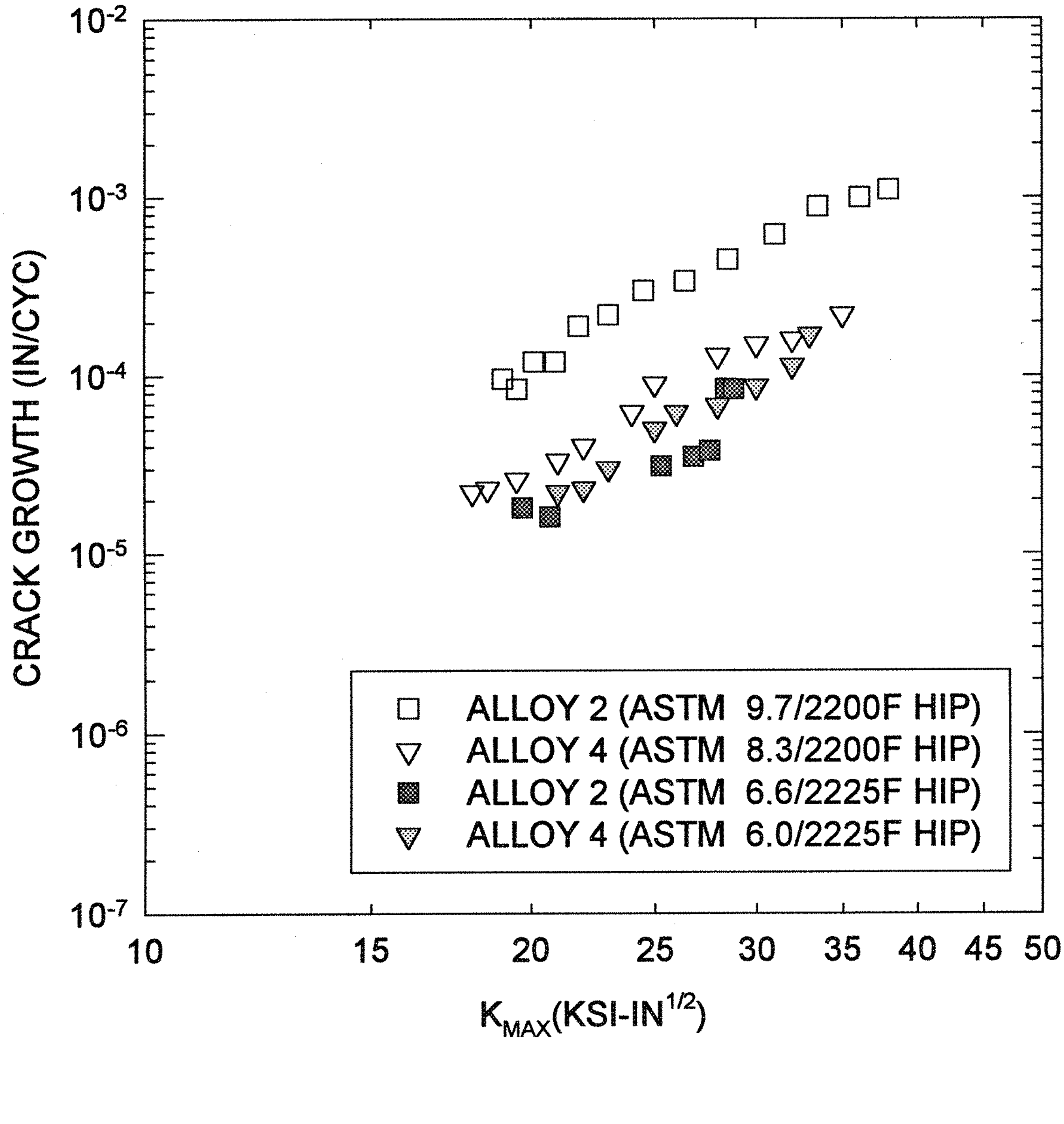


Fig. 7 Grain size effects on dwell crack growth rates.



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13. ABSTRACT *(Maximum 200 words)*

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